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1. Introduction

The spheromak [1], with its simply connected geometry, holds promise as a less expensive fusion reactor. It has reasonably good plasma beta and can be formed and sustained in steady state with a magnetized coaxial plasma gun. The Sustained Spheromak Physics Experiment [2] (SSPX) shown in Fig. 1 was constructed to investigate the key issues of magnetic field generation and energy confinement. In addition to the coaxial gun, nine magnetic field coils are utilized to shape the vacuum magnetic flux. This flexibility allows operation in many different regimes producing very different plasma characteristics. Pulse length is extended and magnetic field strength is increased. Improved surface conditioning produces plasmas with low impurity content, and higher electron temperature, T_e. Electron heat transport within the separatrix is reduced by a factor of 4. The results strongly suggest the existence of closed flux surfaces even though the plasma is connected to the coaxial source. The CORSICA Grad-Shafranov 2-d equilibrium code [2] with data from edge magnetic probes along with T_e and electron density n_e from Thomson scattering is used to calculate internal profiles: normalized current $\lambda = \mu_0 \mathbf{J}/\mathbf{B}$, safety factor = q, ohmic heating, thermal energy density, and thermal diffusivity = χ_e. Ohmic heating is calculated by assuming spatially constant Spitzer resistivity with $Z_{eff} = 2.3$ estimated by VUV spectroscopy.

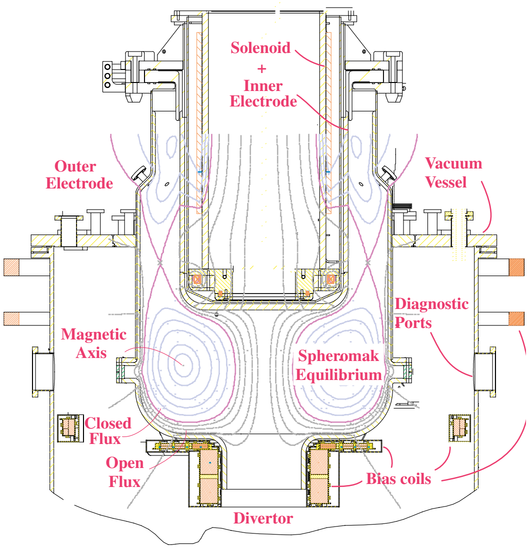

Figure 1. The SSPX Spheromak

2. Improved Confinement in SSPX

A time history representative of best confinement is shown in Fig.2. Highest T_e is measured when edge magnetic fluctuation amplitude ($|\delta B/B|_{rms}$) is lowest and spatial profiles during this time are shown in Fig.3. Improvements were produced by higher formation bank current (first pulse in Fig. 2a), longer discharges (upgraded sustaining bank pulse-forming network), and additional tuning of edge current and bias flux to minimize $|\delta B/B|_{rms}$. Also necessary are low densities and very clean conditions achieved by a rigorous program of good vacuum practices, baking, glow discharge cleaning, and Titanium gettering of the flux conserver every third shot [3]. Saturation of the gettered surfaces is readily indicated by increased n_e and H_α radiation.

The spheromak is formed by the first current pulse and then slowly decays (Fig 2c). Higher initial formation bank current produces higher initial magnetic field and higher T_e. The decay is stabilized and fluctuations minimized by programming the edge current and bias flux to produce a slightly peaked to nearly flat λ-profile (Fig. 3c). The discharge evolves through an optimum profile indicated by a minimum in $|\delta B/B|_{rms}$ (shaded region in Fig. 2) During this time, the q profile across the plasma is also slightly peaked

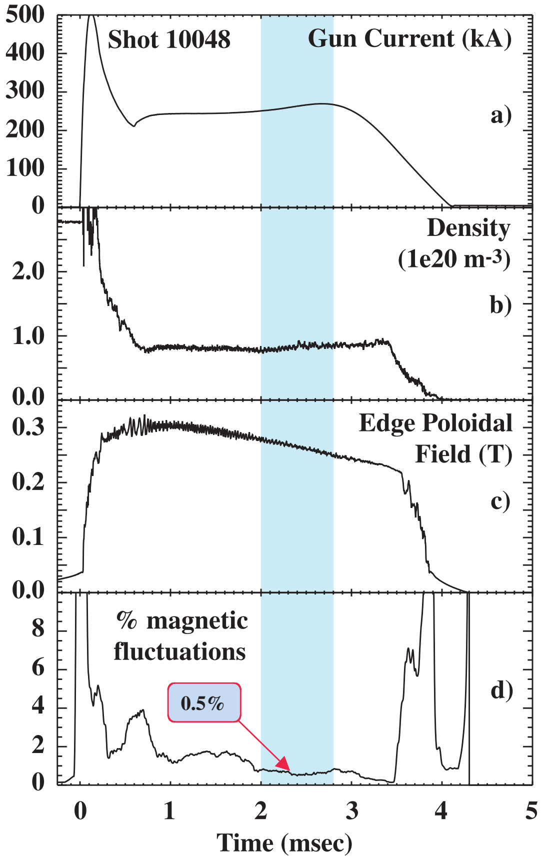

Figure 2. Time evolution of high T_e shot.

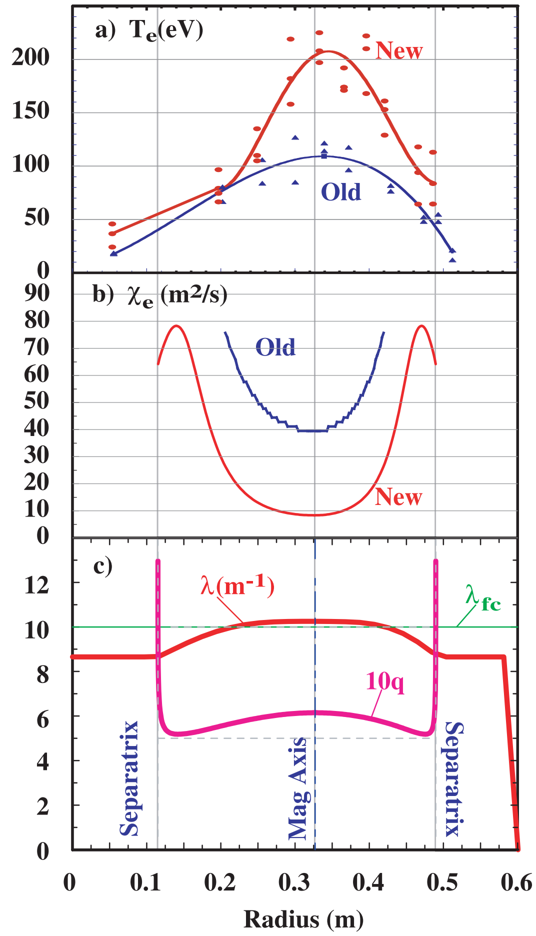

Figure 3. Spatial profiles of a) T_e, b) thermal diffusivity, and c) CORSICA-inferred λ and safety factor q.

and lies between the two lowest order resonant surfaces with $1/2 < q < 2/3$ ($q = n/m$ where n = toroidal mode and m = poloidal mode). Significantly, the $n = 2$ mode is seen when q in the plasma exceeds 2/3 providing useful bench-marking for the CORSICA equilibrium calculation.

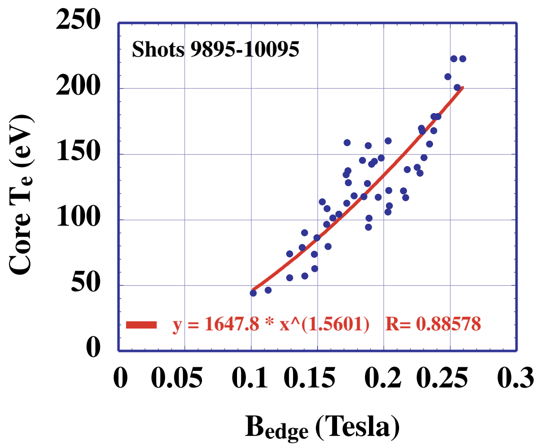

Figure 4. Scaling of Te with B.

T_e has increased over previous results [4] (old vs. new in Fig.3) from 120 eV to > 200 eV with the peak value close to the CORSICA-inferred magnetic axis. χ_e in the core is reduced by a factor of four to < 10 m^2/sec. Ohmic heating in the core is about the same as previously but the edge dissipation is reduced which, when combined with the higher core T_e, doubles the energy confinement time (within the separatrix) to $\tau_E > 200\ \mu S$. A series of shots were analyzed to determine the scaling of T_e with B. Shots had low impurities and similar T_e profiles. Parameters scanned were formation gun flux and current producing shots with $B_{edge} = 0.1$ to 0.25 T. Results (Fig.4) show a very clear correlation of $T_e \sim B^{1.5}$.

4. Field Generation

Since the plasma beta is reasonably good, the physics of magnetic field generation and methods to increase the field become important as a route to obtain higher T_e. Two promising new regimes have been found with improved field generation efficiency (expressed as the current amplification ratio $A_i = I_{tor}/I_{gun}$ where I_{tor} = spheromak toroidal current, I_{gun} = discharge current). In the first regime (Fig.5), reported by Woodruff [5], the gun is operated without the initial high-current pulse. The magnetic field is seen to build until the sustaining bank runs out of charge. This mode produces the highest A_i measured in SSPX but, due to the limited bank charge, it is not known at what level the process will saturate. Another promising method is shown in Fig.6. Here the formation bank is used to supply two pulses on top of the slowly building regime. This offers the intriguing possibility of using pulses spaced close in time to build the field or space the pulses out to provide a quasi-steady operation of pulsed buildup followed by a period of decay and good confinement. We have proposed improvements to the power systems to study these regimes in greater detail.

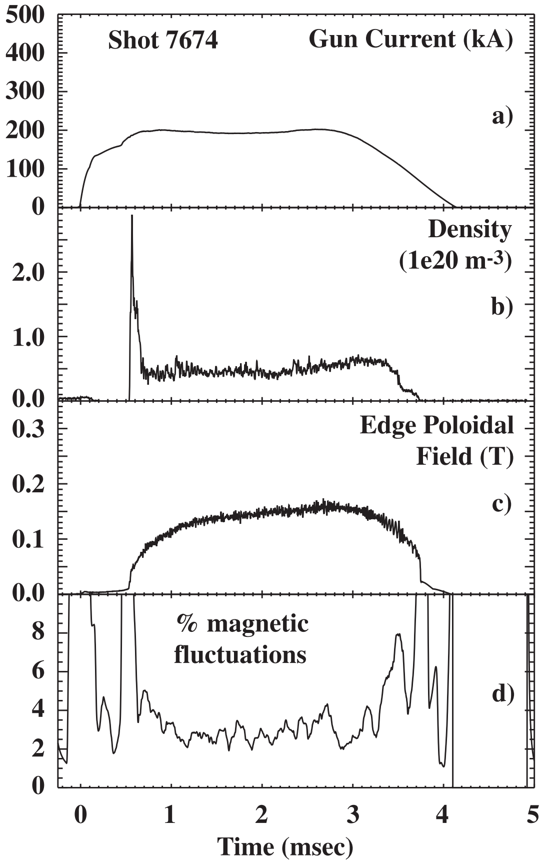

Figure 5. Regime with continuously building magnetic field.

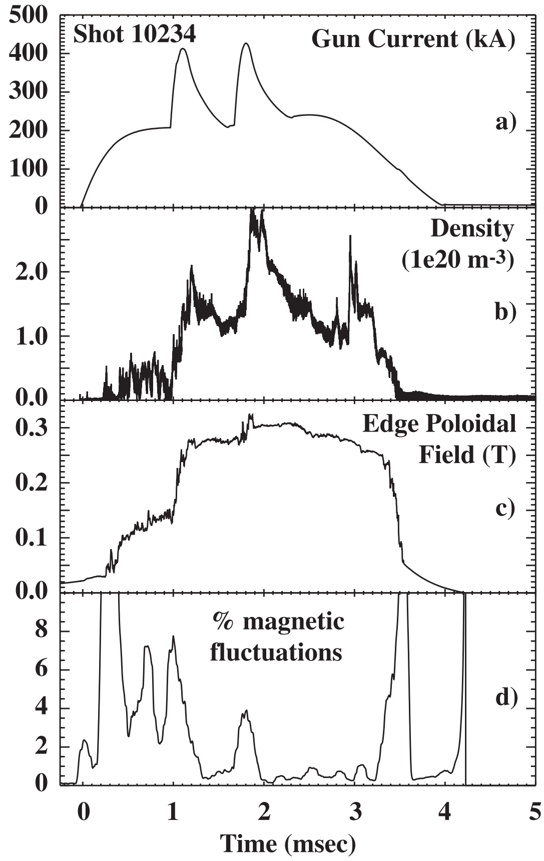

Figure 6. New regime with multiple pulse buildup.

6. Summary

SSPX is producing driven spheromaks with $T_e > 200$ eV. Confinement is improved over previous results with χ_e reduced by a factor of 4. Plasma beta is sufficient for proof of principle experiments and good scaling of temperature is seen with $T_e \sim B^{1.5}$. Promising new regimes are being explored and a new sustainment bank system is planned to study them further.

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